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SYNTHESIS OF TETRA-PHENYLSTANNACYCLOPENTADIENES (STANNOLES). I. --ETC(U)  
APR 81 W A GUSTAVSON, L M PRINCIPE      N00014-77-C-0432  
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  1,1-Dibromo- and 1,1-diiodo-2,3,4,5-tetraphenylstannacyclopentadiene (dibromo- and diiodostannole) formed from controlled phenyltin cleavage of hexaphenylstannole by elemental bromine and iodine, respectively, undergo conventional alkylation by methylolithium to form the expected 1,1-dimethylstannole, but treatment with excess lithium or thallium cyclopentadiene yeilds cubic crystals whose analytical data agree with the formulation X(C <sub>5</sub> H <sub>5</sub> ) <sub>2</sub> SnC <sub>4</sub> H <sub>5</sub> ) <sub>4</sub> M where X=Br, M=Li, Tl and where X=I, M=Li. Infrared v <sub>asym</sub> and v <sub>sym</sub> (Sn-Br) absorptions in the starting dibromostannole are replaced by a single feature at 295 cm <sup>-1</sup> in			

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the X=Br products, and absorptions in the 3000 and 1595-695 cm<sup>-1</sup> region specify the  $\text{h}^1$ -cyclopentadiene nature of the C<sub>5</sub>H<sub>5</sub>Sn unit. The products exhibit two up-field resonances in both the proton and carbon-13 nmr with couplings to tin [ $|^2J(\text{Sn}-\text{Cl}-\text{H})| = 25.4$  Hz for the X=Br, M=Li product and 23.2 Hz for the X=I, M=Li product], and the correct integration ratios for two cyclopentadiene rings per stannole unit. Only slight broadening of the fluxional C<sub>5</sub>H<sub>5</sub> resonances is observed on cooling to -100°C however, the two resonances of equal intensity undergo reversible collapse to a single, unshifted peak at 90° for X=Br and 100°C for X=I. (From the slopes of the Arrhenius plots,  $\Delta E^\ddagger$  is 12.2 and 11.4 Kcal/mol, respectively. The tin-proton coupling constants remain relatively constant over the ca. 200°C range studied. Conductivity data in dilute acetonitrile are typical of weak, 1:1 electrolytes. An ionic formulation is proposed in which a five-coordinated stannacyclopentadiene with one halogen atom remaining from the starting material and containing fluxional,  $\text{h}^1$ -cyclopentadiene groups undergoes pseudorotation to interconvert axial- and equatorial positions in an [R<sub>4</sub>SnX]<sup>-</sup> anion. The appearance of both cyclopentadienyl resonances in the nmr from the onset of the reaction rules out the intermediacy of a 1-( $\text{h}^1$ -C<sub>5</sub>H<sub>5</sub>), 1-halostannole with subsequent adduct formation with C<sub>5</sub>H<sub>5</sub><sup>-</sup> anion. An alternative mechanism would proceed via ( $\text{h}^1$ -C<sub>5</sub>H<sub>5</sub>)<sub>2</sub>SnC<sub>4</sub>(C<sub>6</sub>H<sub>5</sub>)<sub>4</sub> with subsequent metal halide uptake, but the addition of 1,4-dilithio-1,2,3,4-tetraphenylbutadiene-1,3 to bis-( $\text{h}^1$ -cyclopentadienyl)tin dichloride fails to yield a pure material.

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#### Equatorial-Fluxional $\text{h}^1$ -Cyclopentadienyl Groups.

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TECHNICAL REPORT NO. 26

Synthesis of Tetraphenylstannacyclopentadienes (Stannoles).

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1-halo-2,3,4,5-tetraphenylstannole,  
an [R<sub>4</sub>SnX]<sup>-</sup> Anion  
With Pseudorotating Axial- and Equatorial-Fluxional  
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h<sup>1</sup>-Cyclopentadienyl Groups

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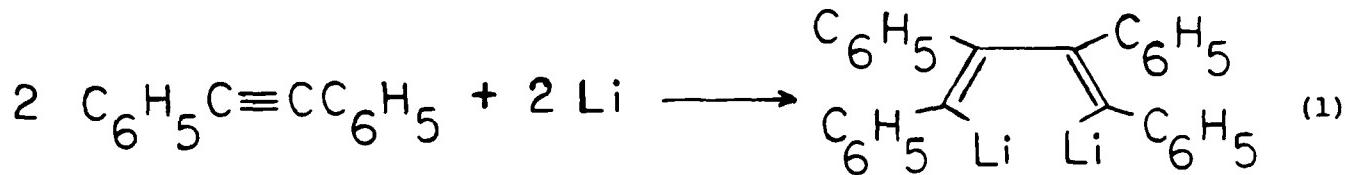
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## ABSTRACT

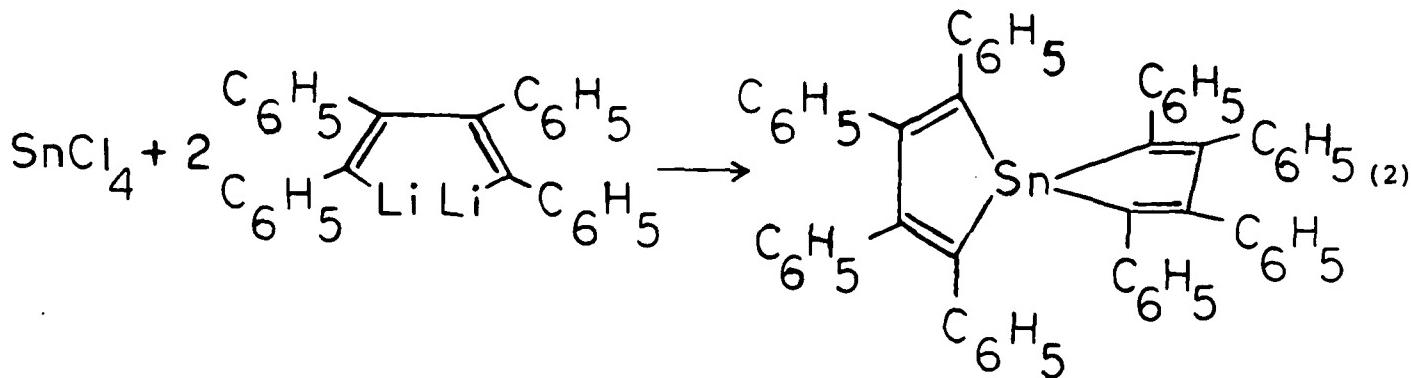
1,1-Dibromo- and 1,1-diodo-2,3,4,5-tetraphenylstannacyclo-pentadiene (dibromo- and diiodostannole) formed from controlled phenyltin cleavage of hexaphenylstannole by elemental bromine and iodine, respectively, undergo conventional alkylation by methyl-lithium to form the expected 1,1-dimethylstannole, but treatment with excess lithium or thallium cyclopentadiene yields cubic crystals whose analytical data agree with the formulation  $X(C_5H_5)_2SnC_4(C_6H_5)_4^M$  where X=Br, M=Li, Tl and where X=I, M=Li. Infrared  $\nu_{asym}$  and  $\nu_{sym}$  (Sn-Br) absorptions in the starting dibromostannole are replaced by a single feature at  $225\text{ cm}^{-1}$  in the X=Br products, and absorptions in the 3000 and  $1595-695\text{ cm}^{-1}$  region specify the  $\underline{h}^1$ -cyclopentadiene nature of the  $C_5H_5Sn$  unit. The products exhibit two upfield resonances in both the proton and carbon-13 nmr with couplings to tin  $|\langle J(^{119}\text{Sn}-C^1-\text{H}) \rangle| = 25.4\text{ Hz}$  for the X=Br, M=Li product and  $23.2\text{ Hz}$  for the X=I, M=Li product], and the correct integration ratios for two cyclopentadiene rings per stannole unit. Only slight broadening of the fluxional  $C_5H_5$  resonances is observed on cooling to  $-100^\circ\text{C}$  however, the two resonances of equal intensity undergo reversible collapse to a single, unshifted peak at  $90^\circ$  for X=Br and  $100^\circ\text{C}$  for X=I. From the slopes of the Arrhenius plots,  $\Delta E^\neq$  is 12.2 and 11.4 Kcal/mol, respectively. The tin-proton coupling constants remain relatively constant over the ca.  $200^\circ\text{C}$  range studied. Conductivity data in dilute acetonitrile are typical of weak, 1:1 electrolytes. An ionic formulation is proposed in which a five-coordinated stannacyclo-pentadiene with one halogen atom remaining from the starting material and containing fluxional,  $\underline{h}^1$ -cyclopentadiene groups undergoes pseudo-

rotation to interconvert axial- and equatorial positions in an  $[R_4SnX]^-$  anion. The appearance of both cyclopentadienyl resonances in the nmr from the onset of the reaction rules out the intermediacy of a  $1-(\underline{h^1-C_5H_5})$ , 1-halostannole, with subsequent adduct formation with  $C_5H_5^-$  anion. An alternative mechanism would proceed via  $(\underline{h^1-C_5H_5})_2SnC_4(C_6H_5)_4$  with subsequent metal halide uptake, but the addition of 1,4-dilithio-1,2,3,4-tetraphenylbutadiene-1,3 to bis- $(\underline{h^1-cyclopentadienyl})$ tin dichloride fails to yield a pure material.

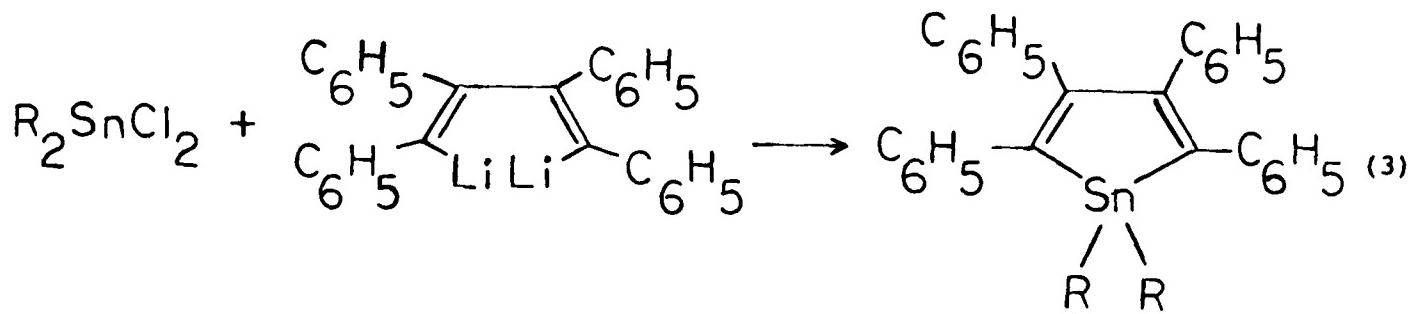
The discovery in 1941 that diphenylacetylene (tolan) undergoes dimerization by the action of lithium metal to form cis-, cis-1,4-dilithio-1,2,3,4-tetraphenylbutadiene:<sup>1</sup>



was developed beginning in 1959 into an apparently general reaction with organometallic and organometaloidal di- and tetrahalides to yield monocyclic and spiro heterocyclopentadienes (metalloles), respectively.<sup>2-3</sup> In the tin series, octaphenyl-1,1-spirobistannole can be prepared from tin(IV) chloride:<sup>2-3</sup>

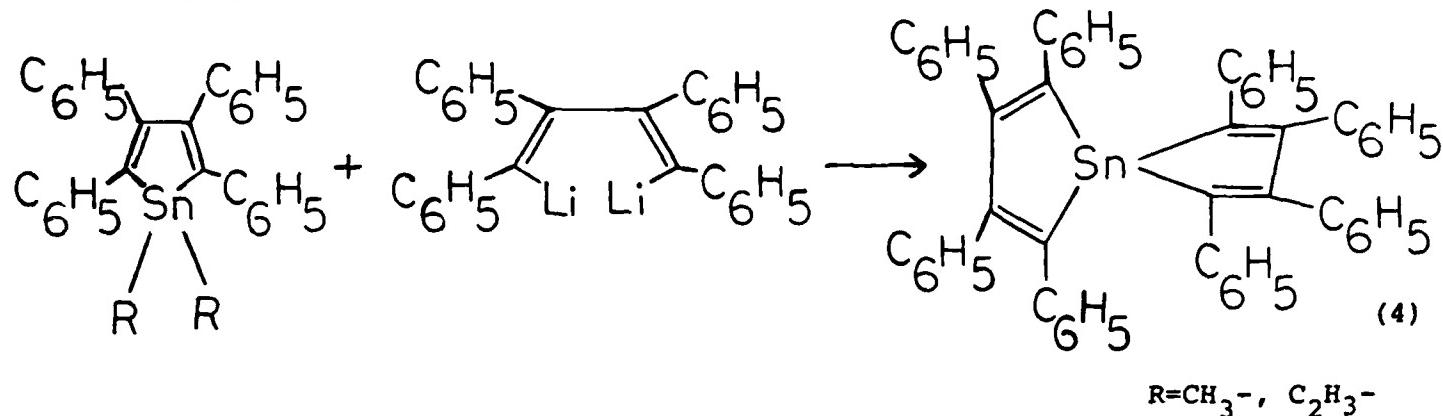


and the 1,1-diorgano-2,3,4,5-tetraphenylstannoles from the corresponding diorganotin(IV) chlorides:

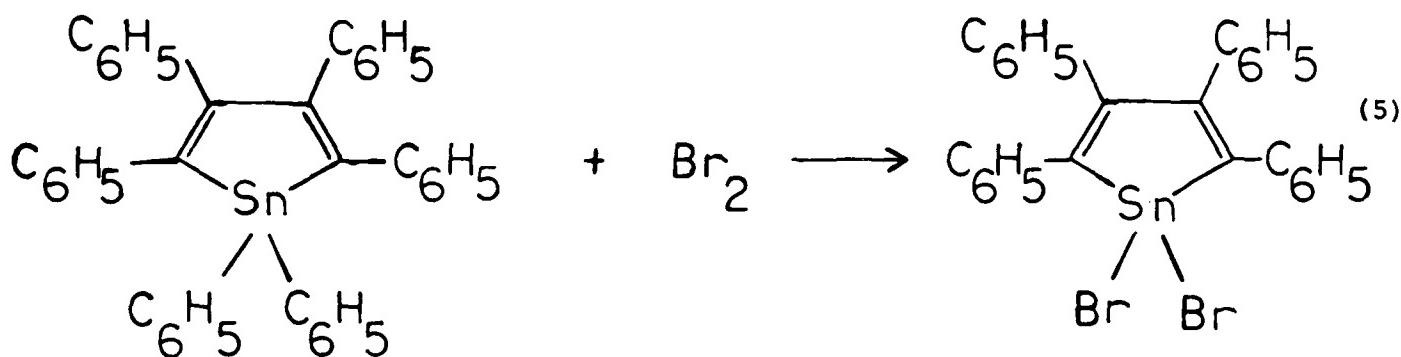


$\text{R} = \text{CH}_3$ <sup>2-5</sup>,  $\text{C}_2\text{H}_5$ <sup>6</sup>,  
 $\text{C}_2\text{H}_3$ <sup>4</sup>,  $\text{C}_6\text{H}_5$ <sup>2-4,7</sup>

When the dilithium reagent is added to the dihalide, the latter is always in excess, and the expected stannoles as shown in Eq. 3 are formed. Reverse addition, on the other hand, leads to alkyltin bond cleavage-cyclization by the dilithium reagent:<sup>4</sup>



The key precursor intermediate in the development of the derivative chemistry of the stannoles is the dihalide. Our synthesis of the dibromo-stannole from phenyltin bond cleavage of the hexaphenylstannole by elementary bromine has been reported in a preliminary form:<sup>8</sup>



In this series of papers we report our results on the derivative chemistry of the stannoles. We begin by describing the synthesis of the 1,1-dihalostannanes and their alkylation which produced an unexpected result.

Experimental Section

Organotin starting materials were of commercial grade and were used without further purification. Melting points were obtained on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Boiling points were determined at constant pressure with a still head thermometer and are uncorrected. Gas chromatographic analyses were performed on a Hewlett-Packard Model 5750 Laboratory Chromatograph equipped with a thermal conductivity detector using helium as the carrier gas. Volatiles were collected at -196°C in U-tubes. Elemental analyses were carried out by Galbraith Laboratory, Inc., Knoxville, TN and by Instranal Laboratory, Inc., Rensselaer, NY. Organotin compounds with high molecular weight (over 700) would often not give consistent analyses. Tin was determined gravimetrically as the oxide, and chlorine, bromine and iodine were determined by potentiometric titration with silver(I) nitrate. Molecular weights were determined in benzene (a suspected carcinogen) on a Hewlett-Packard Model 201A Vapor Pressure Osmometer. Mass spectra were recorded on A.E.I. MS-902 and Hewlett Packard 5985B GC/MS instruments at 70 eV. Nuclear magnetic resonance spectra were recorded on Varian A-60, HA-100 and XL-100 instruments. Tetramethylsilane was used as an external standard, and field width was calibrated with a solution of tetramethylsilane-benzene in carbon tetrachloride. Infrared spectra were recorded in the 4,000 to 200  $\text{cm}^{-1}$  range on Beckman IR-12 or 4250 infrared spectrophotometers and calibrated with polystyrene. Samples were run as liquid smears or Nujol mulls on potassium plates or in polyethylene cells. A Beckman IR-11 spectrophotometer was

used to examine the far infrared region ( $400\text{-}33\text{ cm}^{-1}$ ). Mössbauer spectra were recorded on a constant acceleration, cam-drive spectrometer previously described,<sup>9</sup> with the sample mounted in a cryostat at liquid nitrogen temperature, or on a Ranger Engineering constant acceleration spectrometer equipped with an NaI scintillation counter using  $\text{Ca}^{119m}\text{SnO}_3$  (New England Nuclear Corp.) as both source and standard reference material for zero velocity. Velocity calibration was based on both  $\beta$ -tin and natural iron foils. Data were fitted to Lorentzian curves by standard, non-linear, least squares techniques. The Ranger Engineering variable temperature liquid nitrogen dewar and controller used in this study are regulated by a variable bridge, silicon-controlled-rectifier circuit and are accurate to  $\pm 1^\circ\text{K}$ .

1,4-Dilithio-1,2,3,4-tetraphenylbutadiene<sup>10</sup>

To a solution of diphenylacetylene (tolan) (10.69 g, 0.06 moles) in anhydrous diethyl ether (30 mL) was added lithium wire (0.7 g, 0.1 moles) and the solution stirred at room temperature under a nitrogen atmosphere for four hours. After a ten minute induction period, an intense red color developed, and a yellow solid began to precipitate. This induction time increased significantly with decreasing diphenylacetylene concentration, and was about 30 minutes for a 0.3 to 0.4 M solution. At concentrations below 0.3 M, it was found that any moisture in the system greatly retarded the rate of reaction. If freshly dried equipment is not used, the surface moisture increases the induction period from ca. 30 minutes to as much as 12 hours. The reaction is initially mildly exothermic, and if the concentration of diphenylacetylene

is doubled, cooling with a rapid flow of nitrogen gas becomes necessary.

This procedure is favored over previous methods<sup>1,7</sup> because the precautions necessary to exclude water are much less stringent.

1,1,2,3,4,5-Hexaphenylstannole<sup>2-3,4,7,11</sup>

Diphenyltin dichloride (10.32 g, 0.03 moles) was placed in a three-neck flask equipped with a pressure-equilizing funnel, condenser, and gas inlet tube, and dissolved in freshly distilled tetrahydrofuran (200 mL). A solution of the dilithium reagent was then added to the addition funnel via a hypodermic syringe. This technique separated the excess lithium which remains behind. The red solution and yellow precipitate were then added dropwise to the colorless diphenyltin dichloride solution. An additional 100 mL of diethyl ether was used to transfer the dilithio compound to the organotin solution, which was cooled in an ice bath during the addition. The reaction was mildly exothermic. The resulting green-yellow solution was stirred under nitrogen at reflux for two hours. The ether was removed in vacuo, dichloromethane (250 mL) was added to the residue, and the resulting suspension was filtered. After concentration to ca. 75 mL, absolute ethanol (100 mL) was added. The yellow title compound precipitated upon cooling with Dry Ice. Recrystallization from dichloromethane/ethanol (1:1) resulted in a yellow solid (m.p. 172-73°C), in a yield of 65% based on tolan. The compound was identified by comparison of melting point<sup>2,3,4,7</sup> and Mössbauer (I.S. = 1.39±0.02 mm/s<sup>4</sup>) data with an authentic sample.

An additional tin-containing white powder (m.p. 108-110°C) was isolated in 20% yield based on tolan during an attempt to increase the yield of hexaphenylstannole. The Mössbauer spectrum contained

a doublet with I.S. of  $1.31 \pm 0.02$  and Q.S. of  $2.77 \pm 0.04$  mm/s, and the infrared spectrum contained prominent bands at 3060(w), 3040(w), 1600(m), 1575(w), 1432(m), 1075(m), 1023(m), 1000(m), 730(s) 695(s), and 440(s)  $\text{cm}^{-1}$ . The 1,2,3,4-tetraphenyl-cis, cis-1,3-butadienyl-diphenyltin chloride structure is consistent with these data. Anal. calcd. for  $C_{40}H_{31}ClSn$ : C, 72.18; H, 4.66; Cl, 5.26; Sn, 17.89%; Found: C, 69.87; H, 4.51; Cl, 4.92; Sn, 17.05%.

1,1-Dibromo-2,3,4,5-tetraphenylstannole<sup>8</sup>

A solution of hexaphenylstannole (23.5 g, 37.3 mmoles) in carbon tetrachloride (200 mL) was cooled in a Dry Ice-acetone bath to -30° to -40°C under a nitrogen atmosphere, and bromine (12.0 g, 75.0 mmoles) in carbon tetrachloride (200 mL) added dropwise. The original yellow-green color lightened with the addition of the halogen. The rate of decolorization decreased after half of the bromine had been added, and the remainder of the reaction was carried out at -20 to -30°C for a period of two hours. The color of the solution passed from yellow-green to white to light brown to reddish-orange. The cloudy solution became clear when it was allowed to warm to room temperature. The solvent was then stripped in vacuo to leave a yellow colored oil which was dissolved in a methylene chloride/ethanol mixture to give white crystals (22.5 g, 35.4 mmoles, m.p. 167.5-168.0°C with decomposition) in 95% yield based on hexaphenylstannole. The concentrated mother liquor was found to contain bromobenzene, identified by its infrared spectrum.

The Mössbauer spectrum contained a doublet with I.S. of  $1.48 \pm 0.03$  and Q.S. of  $2.88 \pm 0.06$  mm/s. The infrared spectrum contained prominent bands at 3075(w,b), 3050(w,b), 1600 (w,sh), 1575(w,b), 1485 (w,b), 1445(s,b), 763(m), 732(s,b), 692(s), 576(m), 553(s), 525(m),

445(m), 330(w,b), 271(m), 252(s), 232(s), and 194(m)  $\text{cm}^{-1}$ . The mass spectrum contained fragments up to m/e = 638. An abundant, tin-containing fragment appeared at m/e = 356, with a less abundant fragment at m/e = 631. Anal. Calcd. for  $\text{C}_{28}\text{H}_{20}\text{SnBr}_2$ : C, 52.96; H, 3.16; Sn, 18.69; mol. wt., 634.97. Found: C, 51.69; H, 3.19; Sn, 18.21; mol. wt., 636).

1,1-Diodo-2,3,4,5-tetraphenylstannole

Hexaphenylstannole (5.9 g, 9.3 mmoles) was dissolved in carbon tetrachloride (50 mL) and cooled while stirring under nitrogen to 0°C in an ice bath. To this was added a solution of iodine (4.8 g, 18.75 mmoles) in carbon tetrachloride (150 mL). The color of the original solution lightened with the addition of iodine, passing from yellow to orange to pink to red to purple. The solution was stirred under nitrogen at room temperature for two hours after the addition of the iodine was complete, the solvent was removed in vacuo, and the remaining red-brown oil was dissolved in methylene chloride and filtered. Precipitation resulted with the addition of absolute ethanol and cooling in Dry Ice. After recrystallization from methylene chloride/ethanol a white solid was obtained (m.p. 167-168°C, 5.02 g, 74% yield). The mother liquor from the solid was concentrated and found to contain iodobenzene, identified by its infrared spectrum.

The infrared spectrum contained prominent bands at 3050(w,b), 1600(w), 1574(w), 1490(w), 1442(m), 762(m), 731(s), 695(s), 565(m), 548(s), 513(m), 444(m), 345(w), 184(m), and 80(w)  $\text{cm}^{-1}$ . The Mössbauer spectrum was a doublet with I.S. of  $1.61 \pm 0.03$  and Q.S. of  $2.32 \pm 0.06$  mm/s. Anal. Calcd. for  $\text{C}_{28}\text{H}_{20}\text{SnI}_2$ : C, 46.10; H, 2.74; Sn, 16.32; I, 34.84%; Found: C, 45.77; H, 2.82; I, 36.62; Sn, 15.79%.

1,1-Dimethyl-2,3,4,5-tetraphenylstannole<sup>2-5</sup>

Methyllithium in ether (8.29 mL, 17.75 mmoles) was added dropwise to an ether solution of dibromotetraphenylstannole (4.00 g, 6.26 mmoles). The reaction was cooled in a Dry-Ice/acetone bath under nitrogen, and the temperature slowly raised to ambient when the solution became a yellowish green color. After removal of the solvent, the residue was treated with toluene (20 mL), and lithium bromide was removed by filtration. 1,1-Dimethyl-2,3,4,5-tetraphenylstannole was precipitated and washed with hexane to give yellow crystals (1.2 g, 2.38 mmoles) (m.p. 189.5 -189.0°C vs. lit.<sup>5</sup> 185-192°C) in 37.8% yield. The infrared spectrum consisted of prominent absorptions at 3060(w), 3040(w), 1600(m), 1575(w), 1450(m), 1265(w), 1150(w), 1070(m), 1020(m), 919(m), 880(w), 840(w), 780(m), 759(s), 745(m), 729(s), 690(s), 540(s), 520(s), 510(m) and 400(w)  $\text{cm}^{-1}$  was consistent with this formulation.<sup>5</sup> The nmr spectrum in  $\text{CDCl}_3$  contained a sharp singlet of methyl proton resonance at  $\delta=0.65$  with  $|^2J(^{119}\text{Sn}-\text{C}-^1\text{H})| = 56.2$  Hz, in addition to the phenyl group proton multiplet, and integration gave a ratio of 3.62:1 for phenyl:methyl protons (calcd. 3.33:1).

Lithium 1,1-Di- $^1\text{h}$ -cyclopentadienyl-1-bromo-2,3,4,5-tetraphenylstannole

(a) Lithiation of Cyclopentadiene<sup>12</sup>

Technical dicyclopentadiene (100 ml, 87.5 g) was placed in a 250 mL, one-necked, round-bottom flask equipped with a calcium chloride drying tube and a Newman stopcock-type distilling head (Ace Glass Co.) and 100 mm Vigreux column with the receiver in a Dry Ice bath. The flask containing dicyclopentadiene was heated to 160°C until the cyclopentadiene distilled smoothly at 38-46°C and a little dicyclopentadiene refluxed from the cold-finger condenser.

Freshly cracked cyclopentadiene monomer (1.30 ml, 15.75 mmoles) in tetrahydrofuran (30 mL) was chilled in a Dry Ice bath and treated with n-butyllithium (6.10 ml, 1.6 M, 9.76 mmoles) dropwise at -60°

to -70°. The resulting clear solution then was allowed to warm to room temperature with stirring.

(b) Formation of Lithium 1,1-Di-<sup>1</sup>-cyclopentadienyl-1-bromo-2,3,4,5-tetraphenylstannole

To a solution of lithium cyclopentadiene was added dibromo-tetraphenylstannole (3.0 g, 4.72 mmoles) at room temperature to give a light brown solution which was stirred under argon for three hours. The hexane-tetrahydrofuran solvent was removed in vacuo, and the yellowish-white solid was treated with toluene (20 mL) and the lithium bromide filtered through a Schlenk tube (Ace Glass Co. Model No. 7759) and the filtrate collected in the Schlenk reaction vessel (Ace Glass Co. Model No. 7756) and concentrated to a volume of 10 mL under vacuum before adding hexane (7 mL). A tan colored solid was obtained by cooling the mixture to Dry Ice temperature for one hour. Recrystallization from toluene-hexane required seven days to give hexagonal shaped, tan colored crystals (0.8 g, 1.16 mmoles) which start to shrink at 158.5° and decomposed at 160.5° to give a bright red colored material.

The infrared spectrum showed bands at 3060(w,b), 1595(w), 1570(w), 1485(m), 1524(m), 1027(m), 880(s,d), 755(s,sh), 710(s), 695(s), 578(s,sh), 555(m), 335(s,sh), 252(m) and 225(w)  $\text{cm}^{-1}$ . The Mössbauer spectrum was a doublet with I.S.  $1.41 \pm 0.06$  and Q.S. of  $1.03 \pm 0.12$  mm/s. The proton and carbon-13 nmr spectra at room temperature appear similar, with two upfield resonances ascribable to the tin-cyclopentadienyl system in addition to the phenyl group multiplet  $^1\text{H}$ :  $\delta = 4.38$  and  $4.13$  (in toluence, or  $4.28$  and  $4.06$  in  $\text{CDCl}_3$ ),  $|^2J(^{119}\text{Sn}-^1\text{H})| = 25.4$  Hz at  $40^\circ\text{C}$ ;  $^{13}\text{C}$ :  $114.3$  and  $114.8$  ppm (TMS standard),  $|^2J(^{119}\text{Sn}-^{13}\text{C})| = 30.2$  Hz at ambient. The integration ratio

(2.0:1 calcd; 2.2:1 found) correspond to two cyclopentadiene groups per stannole ring. The temperature-dependent nmr spectrum showed that the two cyclopentadienyl singlets coalesce at 90°C to give one sharp singlet at 5.92 ppm. Anal. Calcd. for  $C_{38}H_{30}BrSnLi$ : C, 65.94; H, 4.37; Sn, 17.15; Li, 1.00. Found: C, 68.13; H, 4.48; Sn, 17.53; Li, 0.69%.

Lithium 1,1-Dicyclopentadienyl-1-iodo-2,3,4,5-tetraphenylstannole

Freshly cracked cyclopentadiene monomer (1.30 mL, 15.75 mmoles) in tetrahydrofuran (30 mL) was cooled in a Dry Ice/acetone bath and treated with n-butyllithium (2.76 mL, 3.53 M in hexane, 9.76 mmoles) dropwise at -60° to -70°C. The resulting clear solution was then allowed to warm to room temperature with stirring under a nitrogen atmosphere.

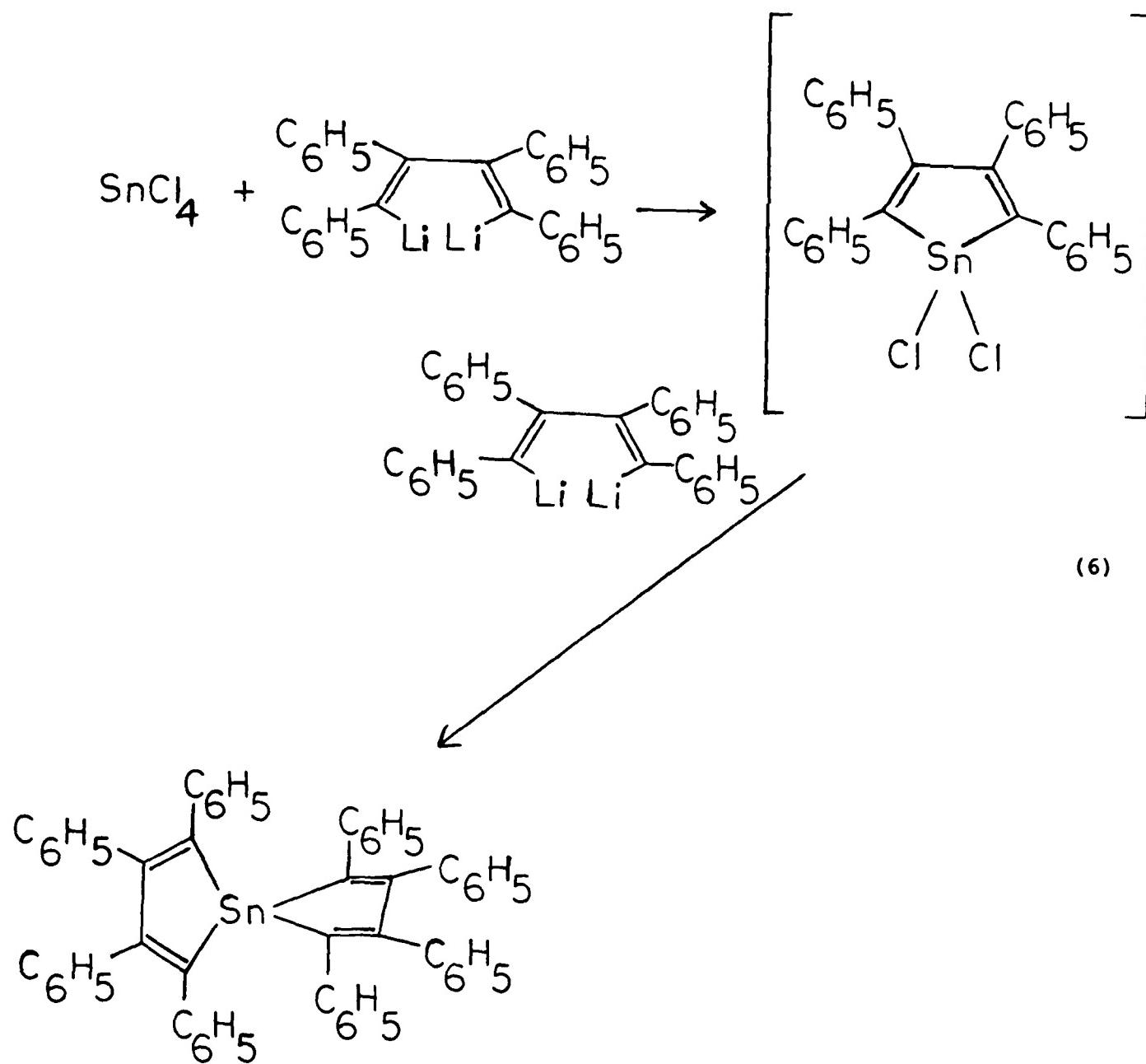
To the solution of lithium cyclopentadiene was added diiodo-tetraphenylstannole (3.44 g, 4.72 mmoles) at room temperature to give a light brown colored solution which was stirred under nitrogen for four hours. The tetrahydrofuran-hexane solvent was removed in vacuo, and the light brown colored solid was treated with toluene (30 mL), and the lithium iodide removed by filtration under nitrogen. The solution was concentrated to 10 mL under vacuum and hexane (10 mL) added. A light brown colored solid was obtained by cooling to Dry Ice temperature (0.69 g, 0.94 mmoles, 20% yield). The solid began to melt at 153°C and decomposed at 156°C.

The infrared spectrum showed bands at 3060(w), 1595(m), 1575(m), 1485(m), 1442(s), 1075(m), 1025(s), 914(m), 883(s), 785(s), 753(s), 726(s), 695(s), 581(s), 552(s), 332(m), 328(s), and 255(m)  $\text{cm}^{-1}$ . The Mössbauer spectrum was a doublet with I.S.  $1.49 \pm 0.03$  and Q.S.  $0.96 \pm 0.05$  mm/s. The proton nmr spectrum at room temperature contained

two resonances attributed to the tin-cyclopentadienyl system in addition to the phenyl group multiplet. The resonances were located at  $\delta=4.54$  and 4.21 ppm (relative to TMS) in  $\text{CDCl}_3$ . The temperature-dependent nmr spectra showed that these two resonances coalesce to give one sharp singlet at  $100^\circ\text{C}$ . Anal. Calcd. for  $\text{C}_{38}\text{H}_{30}\text{SnILi}$ : C, 61.71; H, 4.06; Sn, 16.10; I, 17.19. Found: C, 62.93; H, 4.32; Sn, 15.62; I, 16.43%.

#### Discussion

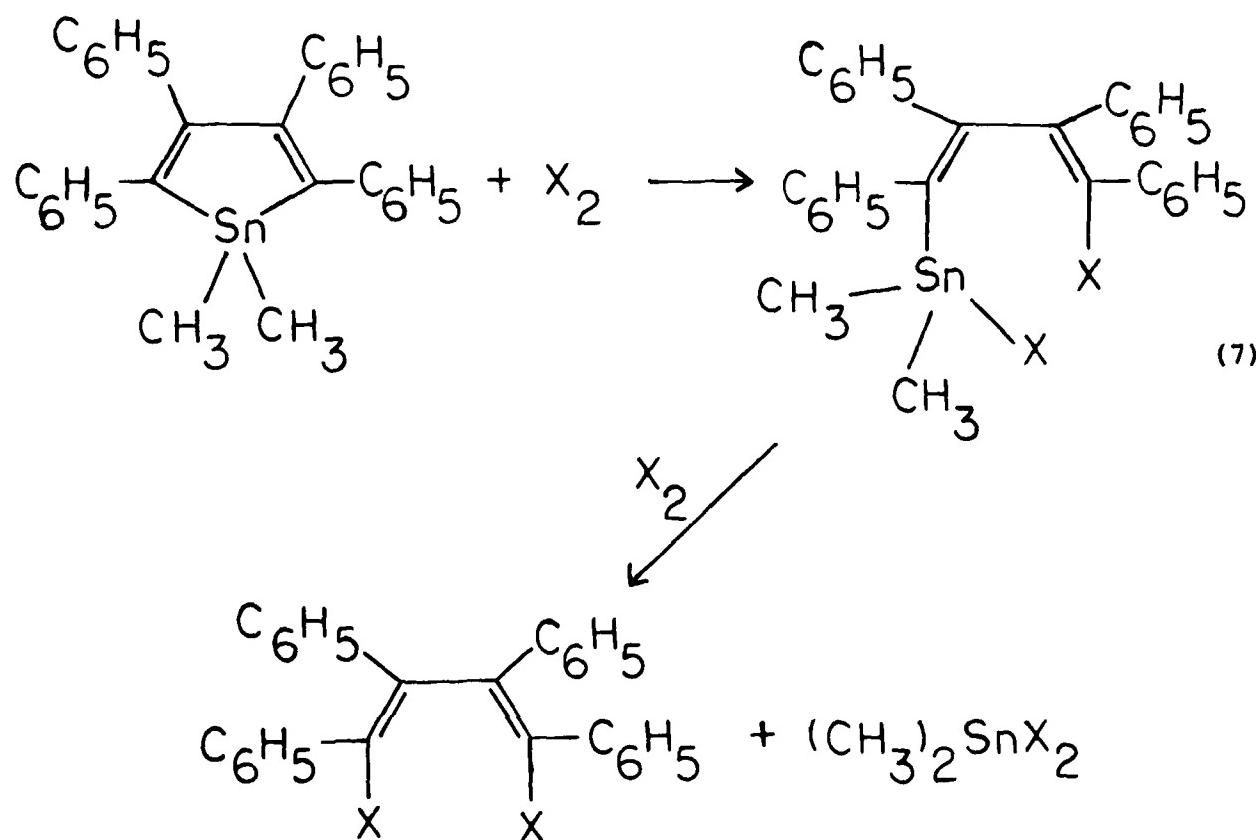
The key step in working out the derivative chemistry of the stannoles is the development of a convenient synthesis of a 1,1-dihalostannole. While in the initial syntheses of the metalloles it was assumed that the 1,1-dichlorostannole was formed as an intermediate en route to the spiro-compound:



and 1,1-dibromo-2,3,4,5-tetraphenylcyclopentadiene could be prepared  
by the addition of carbon tetrabromide to 1,4-dilithio-2,3,4,5-tetra-

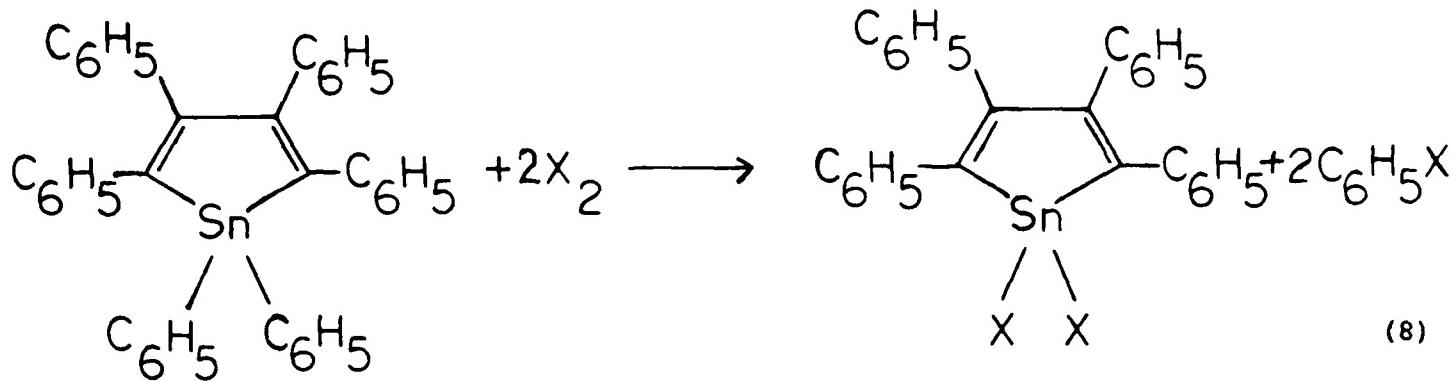
phenylbutadiene,<sup>7</sup> and the analogous dichlorogermmole by the addition of the dilithio reagent to germanium tetrachloride,<sup>13</sup> all attempts to isolate the 1,1-dichlorostannole from the synthesis depicted in Eq. 6 or by other routes have thus far failed.

Instead, advantage can be taken of the well-worked out cleavage of tin-carbon bonds by elemental halogens. In these reactions  $R_4Sn$  species react stepwise, but the last two groups usually resist cleavage somewhat. Thus,  $R_2SnX_2$  compounds can be prepared in this manner. The ease of cleavage of the various organic groups from tin is known to decrease in the order: aromatic>vinyl>alkyl.<sup>14-16</sup> In the stannole series the action of elemental halogens on 1,1-dimethyl-2,3,4,5-tetraphenylstannole results in the cleavage of the olefinic ring carbon to tin bonds while preserving the methylin bonds:<sup>5</sup>



$X = Cl, Br, I$

We have found, however, that controlled bromination or iodination of hexaphenylstannole occurs preferentially at the exo-cyclic phenyltin bond to give the desired dihalostannole:



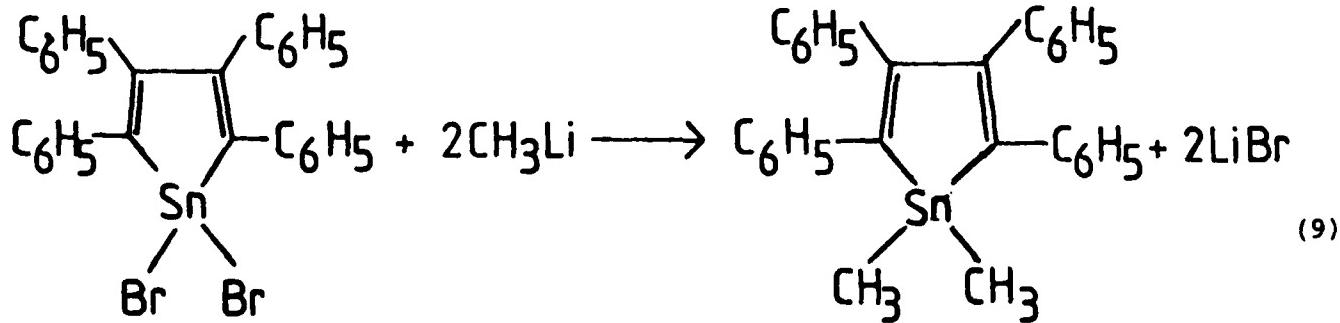
$X = \text{Br}, \text{I}$

The far infrared spectra of these compounds contain absorption bands which can be assigned to the  $\nu_{\text{asym}}(\text{Sn-Br})$  and  $\nu_{\text{sym}}(\text{Sn-Br})$  modes at 252 and  $233 \text{ cm}^{-1}$ , respectively,<sup>17-18</sup> and to the  $\nu_{\text{asym}}(\text{Sn-I})$  and  $\nu_{\text{sym}}(\text{Sn-I})$  modes at 184 and  $180 \text{ cm}^{-1}$ , respectively.<sup>17</sup> The remainder of the spectrum resembles that of hexaphenylstannole.<sup>7</sup> The tin-119 Mössbauer spectra are doublets with Isomer Shift (I.S.) and Quadrupole Splitting (Q.S.) values consistent with four-coordinated, diorganotin(IV) dihalides<sup>19</sup> as shown in Table I. Variable temperature Mössbauer spectroscopy can give further evidence for the structure of organotin solids.<sup>20-21</sup> The plot of the logarithms of the areas under the resonance lines,  $\ln(A_T/A_{77})$ , normalized to the area under the resonance curves at 77 K, vs. temperature for the dibromostannole between 77 and 95 K has a slope of  $-2.22 \times 10^{-2} \text{ K}^{-1}$  (regression analysis data: intercept at  $T=0, 1.719$ ; correlation coefficient,  $r = -0.999$ ; number of

points 3). This rather steep decay of the Mössbauer effect is strong evidence that the dibromostannole exists in its crystal as an assemblage of individual, weakly held monomers.

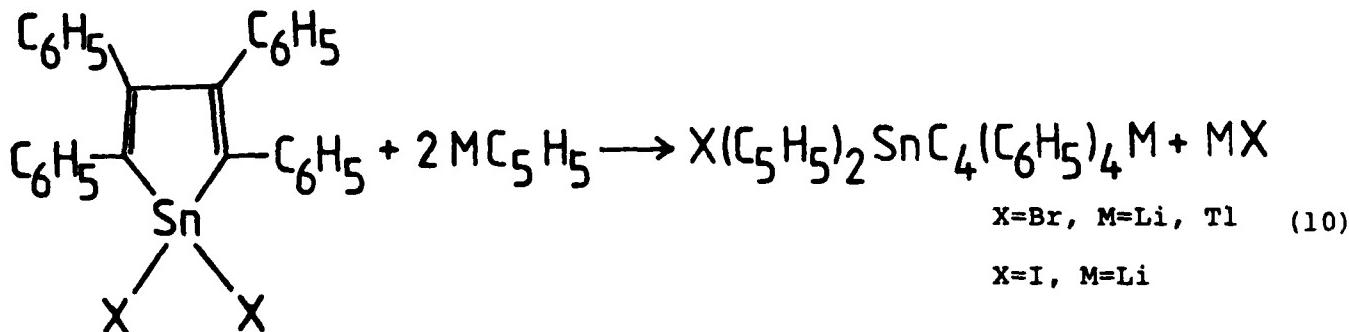
The mass spectra of both the dihalostannoles contain an abundant fragment at  $m/e = 356$  which can be assigned as  $[C_6H_5C=C(C_6H_5)-C(C_6H_5)=CC_6H_5]^+$ ; however, while the dibromo derivative exhibits a tin-bearing fragment centered at  $m/e = 638$ , in the vicinity of the parent peak at  $m/e = 641$  (calcd.), the mass spectrum of the iodo derivative does not contain its parent peak or, indeed, any peaks ascribable to organotin fragments. The most abundant tin-bearing peaks are found centered at  $m/e = 120$ , 247 and 374. These polyisotopic peaks can be assigned to Sn, SnI and SnI<sub>2</sub>, respectively.

The dihalostannoles undergo substitution and complexation reactions typical of a diorganotin dihalide<sup>14-16</sup> except that the stannole ring constrains the tin-carbon bond vectors into configurations different from those encountered in the conventional derivatives, and the unsaturated butadienoid residue exerts an electrical effect on the properties of the tin atom. In addition, the tetraphenyl substitution and presumably planar structure of the stannole ring will have a steric effect on the reactions of the dihalostannoles and on the properties of the resulting products.<sup>22</sup> Nevertheless, alkylation of 1,1-dibromostannole by methyllithium yields the expected 1,1-dimethylstannole:<sup>2-5</sup>



All attempts to reduce the dibromostannole with lithium aluminum hydride resulted in a vile-smelling material which produced severe headaches in our personnel even when handled in an efficient fume-hood. The presumed 1,1-dihydro-2,3,4,5-tetraphenylstannole product was not investigated further.

Treatment of either the dibromo- or diiodostannole with excess lithium cyclopentadiene, from n-butyllithium and cyclopentadiene monomer, at room temperature, followed by removal of the THF-hexane solvent and workup in toluene-hexane which precipitates the lithium halide, results, on the other hand, in the very slow formation of light-brown colored, cubic crystals which analyzed as  $X(C_5H_5)_2SnC_4(C_6H_5)_4Li$  where X = Br, I:



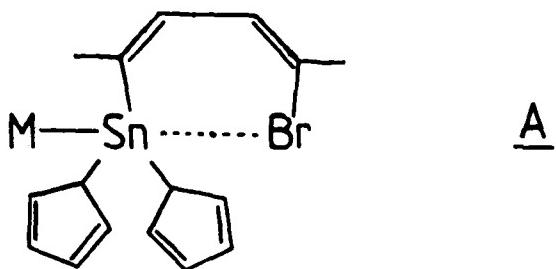
The infrared spectra resemble those of the dihalostannole precursors. In the X=Br derivative, for example, the two bands assigned to the  $\nu_{\text{asym}}$ (Sn-Br) at 253 and  $\nu_{\text{sym}}$ (Sn-Br) at  $240\text{ cm}^{-1}$  are replaced by a single absorption of weaker intensity at  $225\text{ cm}^{-1}$ . Absorptions at  $1485$  and  $1027\text{ cm}^{-1}$  can be assigned to the  $\nu(\text{C-C})$  and ring breathing modes, respectively, of  $\text{h}^1$ -bonded cyclopentadienyl groups.<sup>23</sup> New bands which appear  $335$  and  $332\text{ cm}^{-1}$  in the bromide

and at 332 and 328  $\text{cm}^{-1}$  in the iodide can be assigned to the  $\nu_{\text{asym}}$  ( $\text{Sn-C}_5\text{H}_5-\underline{\text{h}}^1$ ) and  $\nu_{\text{sym}}$  ( $\text{Sn-C}_5\text{H}_5-\underline{\text{h}}^1$ ) modes as found in  $\text{Sn}(\text{C}_5\text{H}_5-\underline{\text{h}}^1)_4$ <sup>24</sup> and the mixed methyl and phenyl derivatives.<sup>25-26</sup> Other absorptions above 3000 and between 1595 and 695  $\text{cm}^{-1}$  specify the diene nature of the cyclopentadienyl ligands.<sup>27-28</sup>

The proton nmr spectra of the two derivatives appear similar at room temperature with two upfield resonances ascribable to the tin-cyclopentadienyl system [for X=Br, 5.72 and 5.94 ppm, for X=I, 5.79 and 5.46 ppm in  $\text{CDCl}_3$  with  $|^2J(^{117,119}\text{Sn}-^1\text{H})| = 25.4$  and 23.2 Hz, respectively, for both resonances at  $40^\circ$ ]. The integration ratio (found: X=Br, 2.5:1; X=I, 2.4:1; calcd 2.0:1) reveals two cyclopentadienyl groups per stannole ring. Data derived from the derivative prepared from the action of two moles of cyclopentadienyl-thallium on the dibromostannole are also similar [5.42 and 5.63 ppm,  $|^2J(^{117,119}\text{Sn}-^1\text{H})| = 26.0$  Hz for both resonances at  $40^\circ$ ]. Both resonances in the cyclopentadienyl region appear simultaneously from initial addition of the  $\text{C}_5\text{H}_5\text{Tl}$ . The proton nmr data are consistent with those for analogous  $\underline{\text{h}}^1$ -cyclopentadienyltin derivatives,<sup>29-31</sup> and the carbon-13 spectrum of the lithium derivative of the dibromo-stannole appears similar, with the two upfield resonances at 114.3 and 114.8 ppm and  $|^2J(^{117,119}\text{Sn}-^{13}\text{C})| = 30.2$  and 26.2 Hz at ambient, respectively. Analogous carbon-13 chemical shifts<sup>32-33</sup> in the series  $(\underline{\text{h}}^1\text{-C}_5\text{H}_5)_n\text{SnR}_{4-n}$  in which R= $\text{CH}_3$  and  $\text{C}_6\text{H}_5$  and n=1-4 lie in the range 113.6-114.3 with the resonance in  $(\underline{\text{h}}^1\text{-C}_5\text{H}_5)_3\text{SnCl}$  at 114.8 ppm.<sup>28</sup> Tin-proton couplings in the related  $(\underline{\text{h}}^1\text{-C}_5\text{H}_5)_2\text{SnBr}_2$  (41.0),<sup>34</sup>  $(\underline{\text{h}}^1\text{-C}_5\text{H}_5)_2\text{SnI}_2$  (37.0)<sup>34</sup> and  $(\underline{\text{h}}^1\text{-C}_5\text{H}_5)_3\text{SnCl}$  (33.5)<sup>33</sup> with  $|^1J(^{117,119}\text{Sn}-^{13}\text{C})|$  for the latter at 26.0 Hz<sup>28</sup> have also been recorded.

The pair of cyclopentadienyl proton resonances undergo only slight broadening at -100° consistent with previous studies on  $\underline{h}^1\text{-C}_5\text{H}_5\text{Sn}$  compounds for which fast, metallotropic 1,2-shifts have been proposed.<sup>31,33</sup> However, as shown in Figure 1 for the lithium derivative of the dibromostannole, the two resonances of equal intensity observed at 40° merge into a single, unshifted peak at 90° (100° for the lithium derivative of the diiodostannole). From the slopes of the Arrhenius plots (-2660K and -2490K for the bromo- and iodo-derivatives, respectively),  $\Delta E^\neq$  is 12.2 and 11.4 Kcal/mol for the processes occurring in the bromo- and iodo-derivatives, respectively. The tin-proton couplings remained relatively constant over ca. 200° temperature range studied, and the changes observed were reversible.

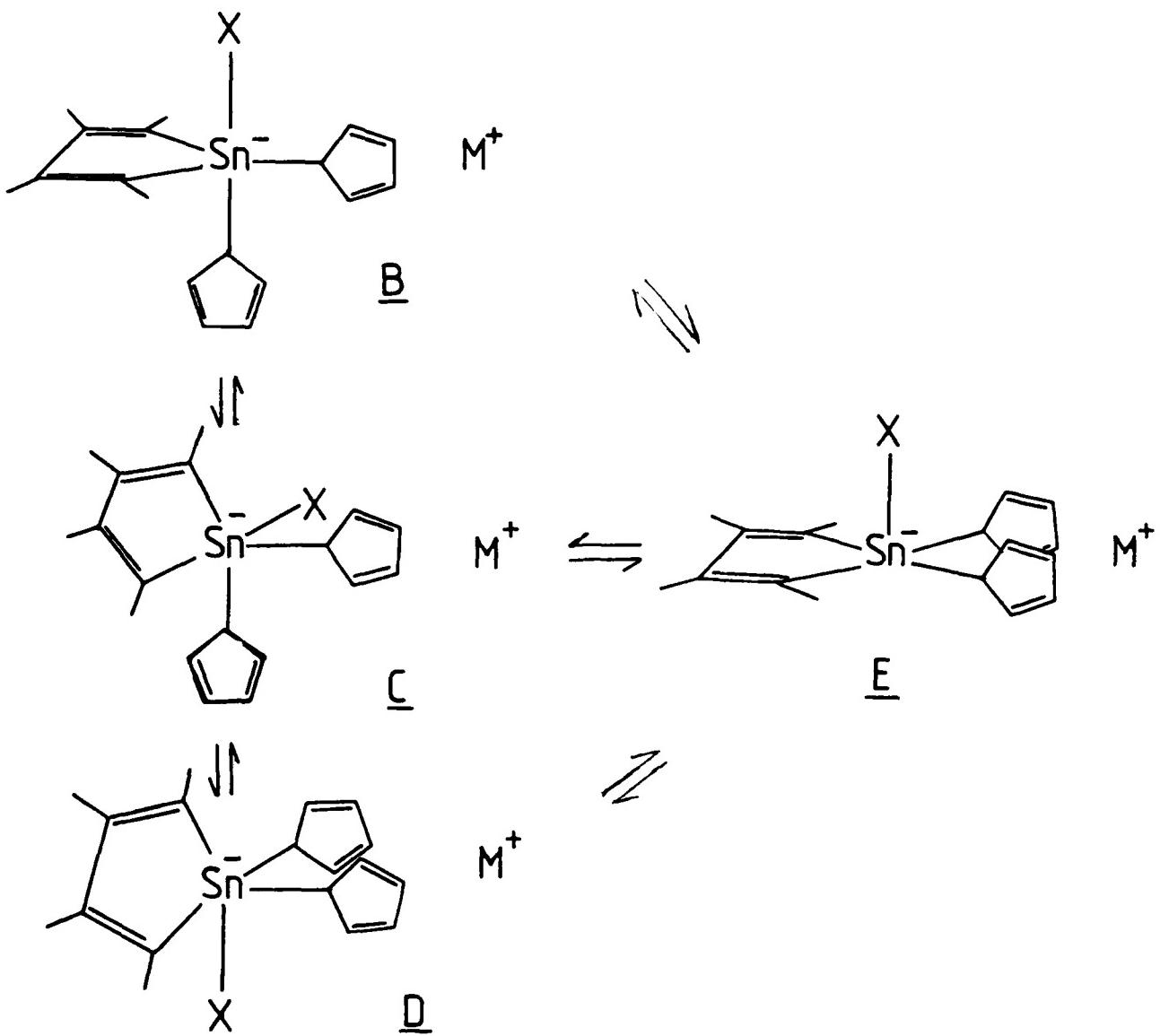
Preservation of the tin-proton couplings through the high temperature region specifies an intramolecular process, and the lack of shift on changing temperature rules out an equilibrium process such as the dissociation of a dimer or ion pair. The origin of the cyclopentadienyl group non-equivalence may lie in hindered diene rotation in an  $\text{LiSnR}_3\text{-XR}$  system arising from intramolecular X-Sn coordination of the type studied in the solid state for 4-bromo-1,2,3,4-tetraphenylbuta-1,3-dienyl)dimethyltin bromide in which a cis-, cis-conformation is adopted to bring the tin and the 4-bromo atoms into contact for intramolecular coordination.<sup>35</sup> Structure A depicts such a situation in which hindered rotation about C(2)-C(3) gives rise to a diene dissymmetry in a compound of the formulation  $\text{MSnR}_3\cdot\text{BrR}'$ :



M=Li, Tl

However, our products show none of the properties of the triorganolithium compounds described in the literature.<sup>36</sup> Moreover, conductivity measurements over the concentration range 1.8 to  $9 \times 10^{-6}$  M for the bromo and 1.8 to  $80 \times 10^{-6}$  M for the iodo-derivative gave  $\Lambda_{\infty} = 123$  and  $133 \text{ ohm}^{-1} \text{ mol}^{-1} \text{ cm}^2$  at infinite dilution in acetonitrile, characteristic of a weak, 1:1 electrolyte. Only negligible conductivity was recorded for the solvent itself, which was freshly distilled from phosphorus pentoxide, and no conductivity was shown by the bromo derivative in nitrobenzene.

Ionic formulations,  $[R_4SnX]^-M^+$  must thus be considered, based upon the usual trigonal bipyramidal arrangement of ligands at the tin atom,<sup>37</sup> as shown in structures B, C and D, and the tetragonal pyramidal E into which they could convert by a pseudorotation mechanism:



Structures B and D are drawn with the halogen,  $X=Br,I$ , in the presumably favored, axially-most-electronegative position, but structure D cannot rationalize the non-equivalence of the two cyclopentadiene groups at tin on the basis of positional isomerism on the trigonal bipyramidal. In structure B the stannole ring spans two equatorial-positions on the trigonal bipyramidal at the tin atom, in C axial-and equatorial-positions are spanned. Based upon structures B and C and hybridization arguments, the downfield resonance in the

carbon-13 spectrum which has the smaller  $|^1J(^{119}Sn-^{13}C)|$  value can be assigned to the axial-cyclopentadiene group. The tin coupling in the proton nmr spectrum is smaller for the downfield resonance only at lower temperatures. Structure D could give rise to the observed cyclopentadienyl group non-equivalence through a stannole ring non-planarity. Such magnetic non-equivalence arising from a preferred dissymmetric diene conformation has been proposed for the related open-chain (4-bromo-1,2,3,4-tetraphenyl-cis-,cis-buta-1,3-dienyl)dimethyltin bromide,<sup>35,38</sup> but is less likely for our heterocycles. While no structural data are available for any of the fourth group metalloles,<sup>37</sup> the heterocyclic ring in the related pentaphenylaluminole diethyl ether complex is completely planar.<sup>39</sup> Structure B in which the stannole ring spans two equatorial-positions would require an unreasonable expansion of the carbon-tin-carbon bond angles. Conversion of structure B to the square pyramidal form E would thus be expected to be accompanied by considerable release of strain. Square pyramidal intermediates have been proposed to rationalize the temperature-dependent proton nmr of 2-biphenyl-bis(4,4-bitolyl)antimony whose singlet total methyl resonance becomes a quartet at -60° ( $\Delta E^\neq = 11.6$  Kcal/mol).<sup>40-41</sup> Solid pentaphenylantimony has a square pyramidal structure.<sup>42-43</sup>

An alternative proposal based upon lithium ion association with the stannole ring in 1,1-bis( $^1h$ -cyclopentadienyl)stannole and a bromide gegenion would rationalize the temperature dependent spectra in terms of a dissociation of the metal-heterocycle complex, but this is ruled out by the lack of chemical shift dependence on temperature, and by the presence of an easily assignable tin-bromide stretching

frequency in the infrared. The chemical shifts of the bromo-derivative are sensitive to the change in metal ion from lithium to thallium, however, and the lack of appreciable conductivity in nitrobenzene and easy solubility in hydrocarbons suggests significant ion pairing.

The synthesis of the  $[X(\underline{h}^1\text{-C}_5\text{H}_5)_2\text{SnC}_4(\text{C}_6\text{H}_5)_4]^-M^+$  species can proceed through either a  $1-(\underline{h}^1\text{-C}_5\text{H}_5)$ , 1-halostannole followed by adduct formation with  $\text{C}_5\text{H}_5^-$  anion or via  $(\underline{h}^1\text{-C}_5\text{H}_5)_2\text{SnC}_4(\text{C}_6\text{H}_5)_4$  with subsequent metal halide uptake. The appearance of both cyclopenta-dienyltin resonances from the onset of reaction rules out the former, and the addition of 1,4-dilithio-1,2,3,4-tetraphenylbuta-1,3-diene to bis-( $\underline{h}^1\text{-cyclopentadienyl}$ )tin dichloride<sup>25</sup> from the redistribution reaction between tetrakis-( $\underline{h}^1\text{-cyclopentadienyl}$ )tin(IV)<sup>24</sup> and tin(IV) chloride did not, in our hands, yield a pure tin-containing material. The oily product gave a Mössbauer spectrum arising from more than one tin site.

Tetraorganotin compounds show no Lewis acid activity, but the as yet unisolated 1,1-bis-( $\underline{h}^1\text{-cyclopentadienyl}$ -2,3,4,5-tetraphenyl-stannole apparently takes up halide ion during its formation from lithium or thallium cyclopentadiene in THF-hexane to form the  $[X(\underline{h}^1\text{-C}_5\text{H}_5)_2\text{SnC}_4(\text{C}_6\text{H}_5)_4]^-$  anion rather than precipitating the metal halide. The addition of pyridine has no effect on these products.

#### Acknowledgement

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Table I

Tin-119m Mossbauer Data for the Dihalostannoles, Their Derivatives

Their Derivatives and Related Organotin(IV) Compounds at

77 K in mm s<sup>-1</sup>

<u>Compound</u>	<u>IS</u>	<u>QS</u>	<u><math>\rho</math></u>
( $^1\text{H-C}_5\text{H}_5$ ) <sub>4</sub> Sn <sup>a</sup>	1.48±0.01		
( $^1\text{H-C}_5\text{H}_5$ ) <sub>2</sub> SnCl <sub>2</sub> <sup>b,c</sup>	1.44±0.03	1.88±0.06	
( $^1\text{H-C}_5\text{H}_5$ ) <sub>2</sub> SnBr <sub>2</sub> <sup>b</sup>	1.58±0.06	1.67±0.12	
( $^1\text{H-C}_5\text{H}_5$ ) <sub>2</sub> SnI <sub>2</sub> <sup>b</sup>	1.68±0.06	1.43±0.12	
(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> SnCl <sub>2</sub> <sup>d,e</sup>	1.49-1.70	3.13-3.81	
(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> SnBr <sub>2</sub> <sup>d,e</sup>	1.68-1.70	3.27-3.48	
(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> SnI <sub>2</sub> <sup>d,e</sup>	1.31-1.78	2.97-3.24	
1,1-Dibromostannole <sup>a</sup>	1.48±0.03	2.88±0.06	1.95
1,1-Diodostannole <sup>a</sup>	1.61±0.03	2.32±0.06	1.44
Lithium 1,1-Di- $^1\text{H}$ -cyclo-pentadienyl-1-bromo-2,3,4,5-tetraphenyl stannole <sup>a</sup>	1.41±0.06	1.03±0.12	0.73
Lithium 1,1-Di- $^1\text{H}$ -cyclo-pentadienyl-1-iodo-2,3,4,5-tetraphenyl stannole <sup>a</sup>	1.49±0.03	0.96±0.05	0.65

<sup>a</sup>This work.<sup>b</sup>Ref. 25.<sup>c</sup>Quoted as IS=1.51±0.06; QS=1.83±0.12 in ref. 25.<sup>d</sup>Ref. 19.<sup>e</sup>Ref. 44.

Table I  
 $^{119m}$ Sn Mössbauer Parameters (mm/s) for Selected  
 Organotin Halides at 77 K

Compound	I.S.	Q.S.	$\rho$	Reference
$\text{Me}_2\text{SnBr}_2$	$1.59 \pm 0.09$	$3.41 \pm 0.09$	2.1	19
$\text{Et}_2\text{SnBr}_2$	$1.68 \pm 0.06$	$3.37 \pm 0.12$	2.0	19
$\text{Et}_2\text{SnI}_2$	$1.72 \pm 0.05$	$2.97 \pm 0.10$	1.7	19
$(\underline{n}\text{-Bu})_2\text{SnBr}_2$	$1.70 \pm 0.15$	$3.15 \pm 0.50$	1.9	19
$(\underline{n}\text{-Bu})_2\text{SnI}_2$	$1.80 \pm 0.07$	$2.90 \pm 0.21$	1.6	19
$\text{Ph}_2\text{SnBr}_2$	$1.43 \pm 0.03$	$2.54 \pm 0.06$	1.8	19
$\text{Ph}_2\text{SnI}_2$	$1.51 \pm 0.04$	$2.38 \pm 0.08$	1.6	19
1,1-Dibromostannole	$1.51 \pm 0.06$	$2.51 \pm 0.12$	1.7	<u>a</u>
1,1-Diodostannole	$1.61 \pm 0.01$	$2.32 \pm 0.02$	1.4	<u>a</u>
Lithium 1,1-Di- $^1\text{h}$ -cyclo-pentadienyl-1-bromo-2,3,4,5-tetraphenyl stannole	$1.41 \pm 0.06$	$1.03 \pm 0.12$	0.73	<u>a</u>
Lithium 1,1-Di- $^1\text{h}$ -cyclo-pentadienyl-1-iodo-2,3,4,5-tetraphenyl stannole	$1.49 \pm 0.03$	$0.96 \pm 0.05$	0.65	<u>a</u>

<sup>a</sup>This work.

